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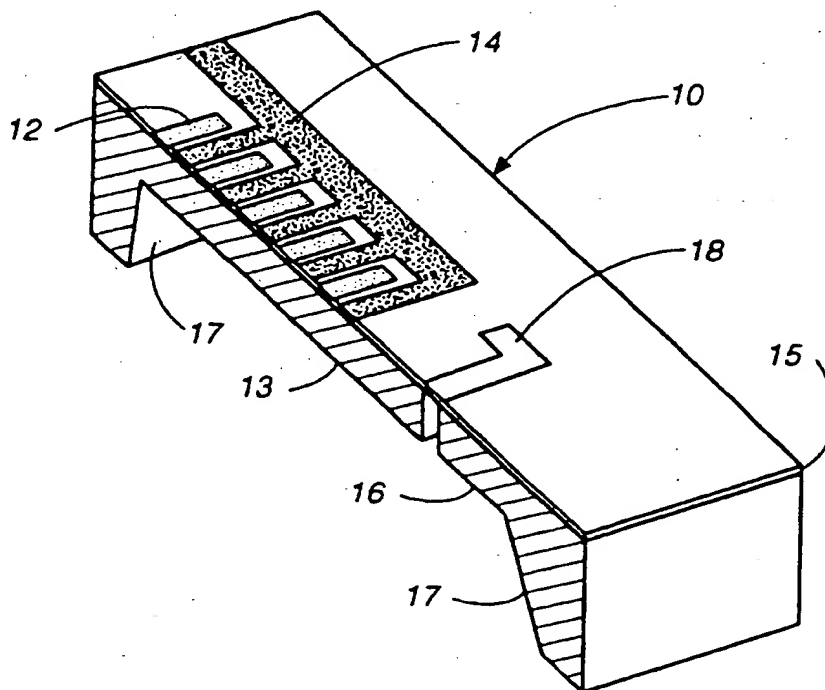
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(54) Title: MICROFABRICATED ACOUSTIC SOURCE AND RECEIVER

(57) Abstract

A microstructure (10) that may be used as an acoustic source or receiver. It comprises a substrate (13) having a thicker section (17) and a thinner section (16) supporting a membrane (15). A window (18) is formed in the thinner section (16). Means (12, 14) are provided for inputting or sensing mechanical energy in the substrate (13) and membrane (15). The microstructure (10) allows for the design of complex mechanical frequency responses for at least partly mechanical signal processing.



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MICROFABRICATED ACOUSTIC SOURCE AND RECEIVER

STATEMENT OF RIGHTS

This invention was made with Government support under a National Science Foundation Grant awarded to the
5 Berkeley Sensor Actuator Center (BSAC). The Government has certain rights to this invention.

BACKGROUND OF THE INVENTION

Currently, acoustic devices such as microphones are geometrically symmetric with little internal
10 structure. They consist of rectangular or circular plates whose motions are detected capacitively, piezoelectrically, or piezoresistively. In its operating frequency range, mechanical response of such a device is a relatively smooth function of frequency.
15 For more complex transfer functions, electronic filters must be used.

Micromachining, on the other hand, allows the fabrication of reproducible microstructures that have complex mechanical transfer functions. Complicating the
20 mechanical designs simplifies the electronics which, in turn, can reduce required power and increase signal-to-noise ratio. This concept may improve performance of hearing aids. Tools such as finite-element methods may be used to predict and tailor the response of a given
25 device.

An object of the present invention is to provide a micromachined acoustic source and receiver.

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Another object of the present invention is to provide a micromachined acoustic source that may be used as a microcutter, microchisel or microhammer.

Yet another object of the present invention is to
5 provide a micromachined structure that may function as a micro-optical component in application of optical phase modulation and beam chopping.

Additional objects and advantages of the invention will be set forth in the description which
10 follows, and in part will be obvious from the description, or may be learned by practice of the invention. The objects and advantages of the invention may be realized and obtained by means of the instrumentalities and combinations particularly pointed
15 out in the claims.

SUMMARY OF THE INVENTION

The present invention is directed to a microfabricated acoustic source or receiver. Acoustic encompasses both audible and ultrasonic sound. It
20 comprises a substrate of a first material having first and second sections wherein the thickness of the first section is greater than the thickness of the second section. A membrane of a second material is supported by the substrate. The thickness of the membrane is less
25 than that of the second section of the substrate. The microstructure further includes a means for inputting or sensing mechanical energy in the substrate and membrane. Additionally in a preselected region of the second section of the substrate, the first material has been
30 removed to form a window section.

The micromachined structure of the present invention allows for the design of complex mechanical frequency responses. It permits signal processing to be transferred, in part, from the electrical to the
35 mechanical domain. It reduces complexity while increasing the signal-to-noise ratio.

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The micromachined structure of the present invention can exhibit a 85 decibel (dB) sound pressure level (9.7kHz and 3Vpp drive voltage) and $900\mu\text{V}/\mu\text{bar}$ sensitivity at its resonant frequency. These resonant frequencies lie in the audio and the ultrasonic range. The device is audible to the ear and sensitive to sound in common room-like surroundings.

The structure may consist of silicon interconnected beams, plates, cantilevers, and silicon nitride thin membranes. Depositing a zinc oxide (ZnO) piezoelectric transduction film or layer allows the structure to be driven electrically. The processing involves bulk micromachining with extensive backside lithography.

The micromachining process permits fabrication of an acoustic receiver consisting of coupled oscillators that can be designed to produce a desired frequency response.

At ultrasonic frequencies, the device can be used as a microcutter, microchisel or microhammer. This may be important in the biological and medical industries for investigating and manipulating tissue, and holds the promise of better control and higher power in microcutting than other technologies such as laser cutting and ablation.

The structure can also include an optically transparent thin film. By exciting mechanical motion in this film, the optical properties of the microstructure may be changed and so affect an optical signal passing through the film. This behavior holds the promise of mass-produced micro-optical components, such as an acousto-optic phase plate.

BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings, which are incorporated in and constitute a part of the specification, schematically illustrate preferred embodiments of the

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present invention, and together with the general description given above and the detailed description of these embodiments given below, serve to explain the principles of the invention.

5 Figure 1A is a schematic representation of an acoustic source and receiver in accordance with the principles of the present invention.

Figure 1B is a view along line 1B-1B of Figure 1A.

10 Figures 2A-2I are process flow diagrams illustrating a process for fabricating an acoustic source and receiver of the present invention.

Figures 3A-3D schematically represent various microstructures that may be fabricated using the process
15 illustrated by Figures 2A - 2I.

Figure 4 graphically represents the sound pressure level of a microstructure of the present invention.

20 Figures 5A and 5B are graphic representations of a microphone and speaker response, respectively, for the notch structure of Figure 3A.

Figure 6 is a graphical representation of displacement for the notch structure of Figure 3A.

25 Figure 7 is a graphical illustration of the speaker response of the cantilever microstructure of Figure 3B.

Figures 8A - 8L are graphical representations of the ABAQUS derived eigenmode shapes and eigen-frequencies.

30 Figure 9A schematically illustrates a microstructure of the present invention used as a surgical cutter.

Figure 9B illustrates the elliptical motion of the microstructure of Figure 9A.

35 Figure 9C is a schematic illustration of an alternative cutting edge of the cutter of Figure 9A.

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Figure 10 is a schematic representation of a circuit for an acoustic receiver functioning as a microphone.

Figure 11 is a schematic representation of a
5 circuit for an acoustic source functioning as a speaker.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

The present invention is directed to a microfabricated acoustic source and receiver. This microstructure may function, for example, as a
10 microphone or speaker at audible frequencies, and as a microcutter at ultrasonic frequencies.

The shape of the microstructure may be selected to produce a particular acoustic response. As shown in Figures 1A and 1B, an acoustic source and receiver 10 of
15 the present invention may comprise interdigitated, transducer fingers 12 and 14. The fingers can be used to input mechanical energy into the microstructure. A piezoelectric ZnO layer sandwiched between aluminum planes, one of which serves as an electrical ground
20 plane, may form the transducer fingers. By way of example, the aluminum planes may each be about .3 microns(μm) thick, and the ZnO film 2 microns thick.

Other transducer patterns and transduction mechanisms, other than piezoelectric, may be used. For
25 example, the transduction mechanism may comprise a thermal stress, electrostriction, magnetostriction, or optical drive system.

Fingers 12 and 14 may function as sense or generating transducers. As will be described below in
30 reference to Figures 10 and 11, if microstructure 10 functions as an acoustic receiver, for example a microphone, fingers 12 and 14 may both act as sense transducers. That is, no drive voltage (V_{pp}) is applied to the fingers, and stresses imparted to the
35 microstructure will cause the transducers to generate an electrical signal. If, on the other hand,

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microstructure 10 functions as an output device or acoustic source, for example a speaker, a drive voltage V_{pp} may be applied to transducers 12 and 14.

Alternatively, one transducer, for example transducer 5 12, may function as a sense electrode to provide feedback control, while the other transducer acts as a generating transducer to which the drive voltage is applied.

The transducer fingers may be formed on a thin 10 silicon plate section 16 of a substrate 13 that also includes a frame or baffle section 17. The plate 16 may be between about 40 and 100 microns thick, and more preferably between about 50 and 70 microns thick.

A silicon nitride membrane or layer 15 may be 15 formed between the fingers and plate 16. Layer 15 may be between about one and four microns thick, and more preferably about 2 microns thick. Membrane 15 may also be formed of other materials such as polysilicon, silicon dioxide or various polymers, and may comprise of 20 sandwich materials of thin layers of many such materials.

The thickness of baffle section 17 may be between about 500 and 550 microns. The frame 17, like plate 16, may be formed of silicon. As mentioned, the frame and 25 plate sections are part of a substrate that supports membrane 15, and transducers 12 and 14. Other materials may be used for plate 16 and frame 17. For example, quartz may be used to give the microstructure different elastic properties.

30 The microstructure 10 also includes a window section 18. Section 18 may be a silicon nitride film that is about 2 microns thick. The window section may be formed, as will be discussed, by removing material from preselected regions of plate section 16. As will 35 be described, the location and pattern of the window section or sections can be selected to tailor the frequency response of the microstructure. As such, a

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desired frequency response may be designed for without the use of complex electronics.

The thin silicon plate configuration of microstructure 10, with very small area connecting silicon nitride, is much stronger than large-area thin membranes. Therefore, microstructure 10 can operate under very rugged conditions.

The fabrication of structure 10 may start with a four-inch silicon wafer 20. As shown in Figure 2A, a 4000 angstrom(A) layer of low-stress silicon nitride 22 may be first deposited on the wafer in an LPCVD furnace. The nitride is patterned using lithography and plasma etching exposing the silicon areas 21 to be removed. As seen in Figure 2B, a small square (or squares) 23 is opened on the top side for silicon membrane thickness control. The wafers are then etched in a KOH bath (Figure 2C). The square is sized so that KOH etching ceases on the top when a certain height pyramid 26 is etched; much larger squares 24 etch on the backside concurrently. When the backside incomplete pyramid 25 encounters top pyramid 26, the transmission of light is observed and the wafer is removed from the etch bath. This method permits control of the silicon membrane thickness to within +/-5 microns.

Next, as shown by Figure 2D, a second layer of -1.5 μ m thick silicon nitride 27 is deposited over the entire wafer. Backside lithography is used to remove this silicon nitride where additional silicon 28 is to be etched (Figure 2E). The plate structure and window section 18 (see Figures 1A and 1B) is then defined by removing the silicon using KOH etching (Figure 2F). The silicon nitride (layer 15), which, as noted, may be about 2 μ m, is strong enough to support the silicon substrate members (plate 16 and baffle 17) and survive further processing steps.

The next steps (Figures 2G-I) involve making the piezoelectric transducer fingers 12 and 14. A 3000A

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thick, aluminum layer with two percent silicon is sputtered on the front of the device. The sputtered aluminum is then patterned using PR lithography to form regions 29. A $2\mu\text{m}$ thick film 30 of ZnO is then RF magnetron sputtered on the wafer. A second film 31 of aluminum is sputtered over the ZnO and is patterned by PR lithography to form the electrical ground plane. This aluminum pattern is then used as a mask to remove the exposed ZnO by etching, allowing electrical contact to the transducers to be made via aluminum regions 29.

Figures 3A-3D show various structures that may be fabricated using the process of Figures 2A-2I. These structures produce different frequency responses. The microstructures illustrated are a notch structure 32, a cantilever structure 34, and structures 36 and 38 with beams of different lengths and widths. The overall transverse dimensions "y" and "x" of the thin silicon plate 16 of these structures may be about 9 millimeter (mm) and 10mm, respectively. The thickness of plate 16 is about 60 microns. These various designs were made to study the effect of beams and cantilevers of different lengths and widths. Transducers 12 and 14 in the shape of interdigitated fingers were used to excite very high-frequency (100kHz and above) modes.

The window section 18 of notch structure 32, as shown in Figure 3A, forms a simple notch in silicon plate 16 spanning two sections of the plate. The window section 18 of microstructure 34 (Figure 3B) forms a cantilevered arrangement wherein transducers 12 and 14 are supported at one end 19 relative to plate 16. Microstructures 36 and 38 (Figures 3C and 3D) show beams of different lengths "l" and widths "w". For example, the lengths "l" of the beams may range from about 1 to 4mm and the widths "w" from about 1 to 2mm.

The following characteristics of the microstructures may be measured: sound pressure level, acoustic input/output response spectrum, and membrane

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deflection. Using a sound pressure level meter, the sound intensity of notch device 32 (Figure 3A) was measured as a function of input voltage versus distance from the device. A pressure level of 85dB was measured about 1 centimeter(cm) away from the device at its 9.7kHz resonance. The device radiated sound isotopically because the wavelength of the flexural wave is much smaller than the acoustic wavelength in air at this frequency. Figure 4 shows the output power level in dBs. As can be seen, the pressure produces a log-like curve which, when plotted in linear pressure units, indicates a linear function of the input drive voltage V_{pp} .

The acoustic output as a function of frequency was also measured for notch structure 32. A microphone was placed 0.5cm above the center of the device to measure its output when a sinusoidal signal from 4 to 50kHz at 1Vpp was applied to the acoustic source. Similarly, the microphone response was tested by applying a calibrated acoustic signal from an external speaker (producing signals from 4 to 20kHz) near the acoustic receiver and measuring the signal generated. The microphone response was $900\mu V/\mu bar$ at 9.4kHz and $160\mu V/\mu bar$ at 5.7kHz. The sensitivity was higher than $40\mu V/\mu bar$ in the range of 6 to 11kHz.

The displacement of notch device 32 was also measured using a laser-amplified feedback interferometer (see Figure 6). The resolution of the interferometer system is -1 nanometer, well below the displacements measured. The quality factors of the resonances were found to range from 20 to 30. Since the thin silicon nitride moves as much as, if not more than, the silicon, the silicon nitride film can be used as a coupling agent between different silicon sections. The displacement at resonance reaches 100nm (at 3Vpp). The displacement was measured at various locations on the device in the frequency range of 10Hz to 52kHz to obtain an estimate

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of the mode shapes. The final goal, however, is to predict a response once a particular structure is given.

The notch structure 32 is complicated due to the asymmetry of the nitride window. The speaker response for the much simpler cantilever-microstructure 34 (Figure 3B) is shown in Figure 7. A B&K microphone was placed 1 mm away from the center of the cantilever to measure the radiated field. The dashed line represents the response in the presence of the silicon nitride window 18 connecting the silicon membrane to the frame. The heavy line shows the response with the nitride window removed. The two curves show that removing the nitride window shifted the response down by 2 to 4kHz. Furthermore, the resonances with the nitride window are broader than those without it. This indicates that the nitride window can play a major role in determining the response of these devices: both as a coupling agent between silicon members and as a damping section, which dampens the resonance of the structure to provide a broader resonance.

To predict the response of a given microstructure, the elasticity theory specialized to layered plates coupled to a fluid such as air can be used. The cantilever structure 34 was modeled in ABAQUS, a finite-element mechanical analysis program. A 20x20 array of nodes was used with 10x10 shell elements. These shell elements consist of 9 nodes. Each shell element was modeled as a 65 μ m thick silicon plate sandwiched between two 1 μ m nitride membranes. The results of an eigenmode analysis appear in Figures 8A - 8L, where the first twelve mode shapes and their respective frequencies are shown. Since the B&K microphone was located 1mm above and near the center of device 34, with its sensitive area (-2mm in diameter) much less than the device area, it is expected that modes that have substantial deflection at the center will contribute more to the measured response. Modes 4,

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5, 8, and 12 (highlighted in Figures 7, 8D, 8E, 8H, and 8L) have displacements that are effectively symmetric with respect to the center of the cantilever and produce large motion there in at least one of the directions.

- 5 As expected, these are the same modes that match with the measured response.

The predicted frequencies are in agreement with the measured response given the resolution bandwidth of the measurement was 1kHz. An error of about +/-500Hz
10 exists in modes 4, 5, 8, and 12. Mode 5 has an error of about 1.1 kHz. Wrong values for material properties (such as the Poisson's ratio for silicon) being entered for the model might be responsible.

In addition to predicting the frequency, a
15 feeling for the relative amplitude at each frequency should be obtained. At large plate wavelengths, the plate looks like a piston which pushes against a large area of air and feels the maximum resistance. This also causes the output to be isotropic as there is no
20 preferred direction. When many wavelengths fit in the plate, the air resistance is lowered as air displaced at one point easily pushes the plate on points half wavelength away as those points displaced in the opposite direction. This lowers the effective pressure.
25 Radiation becomes anisotropic as the wave has a preferred angle of propagation. Figures 8A - 8L show the mode shapes for each mode. The acoustic wavelengths in each direction of the plate can be estimated. As can be seen, modes 4 (Figure 8D) and 5 (Figure 8F) radiate
30 well because they are essentially piston-like, while modes 8 (Figure 8H) and 12 (Figure 8L) do not radiate well because they have many maximums and minimums and are not piston-like.

A micromachined acoustic source and receiver has
35 been described that can produce 85dB sound pressure level (at 7kHz and 3Vpp drive) and 900 μ V/ μ bar sensitivity at its resonant frequency. These

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frequencies lie in the acoustic and low ultrasonic ranges. A cantilever microstructure in a finite-element analysis using shell elements was modeled, which confirms that the elastic shell theory can be used to design a response.

The acoustic source and receiver shows promise in hearing aids and other applications where a compact acoustic source is required. A combination of speaker and microphone on one chip, integrated with other electronics, can be used to measure speed using the doppler effect, or can be used to measure distance. For hearing aid applications, the frequency response can be designed into the mechanical microstructure. Thus, a hearing aid custom-tailored for an individual may be fabricated. Furthermore, the transduction system described herein is mainly capacitive and therefore consumes very little power. This gives the opportunity to make the electronics simpler to reduce the power budget. In addition, unlike other micromachined microphone structures made of thin diaphragms and membranes, this device is made of a relatively thick silicon plate supported by very thin silicon nitride membranes (windows) that can withstand harsh environments.

At ultrasonic frequencies, plate modes in the structure can be excited. Thus, an open-ended plate can be used as a cutter (see Figure 9A). The cutter may be fabricated as described above and include interdigitated transducers and 54. The cutter may include an angled cutting edge 55. The angle θ of the cutting edge can be about 57.3° . An ultrasonic, flexure wave generated at one end of the cutter will travel to cutting end 55, producing an elliptical motion 58 as shown in Figure 9B. This motion can be used to cut soft materials such as tissue. Since the zeroth order antisymmetric Lamb mode has a phase velocity less than that of sound in water, acoustic energy will be trapped

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in the plate while that motion cuts at the cutting end. An alternate cutting edge 56 for the microcutter is shown in Figure 9C. This edge incorporates a beak-like configuration.

5 As a cutter, the present invention holds the promise of cutting biological tissue in diseases like cataracts (most-performed operation in the United States) and clogged arteries. Splicing cells and cutting tissue precisely can be very useful technologies
10 for the biology industry.

 The use of a microstructure, in this example cantilever structure 34, as an acoustic receiver, for instance a microphone, is shown in Figure 10. The transducers 12 and 14 both act as sense electrodes whose
15 output is applied to amplifiers 40 and 41, respectively.

 A circuit for an acoustic source is shown in Figure 11. The source, for example, may function as a speaker or cutter. A voltage source 42 is connected to an impedance matcher 44 through an amplifier 43. The
20 output of the impedance matcher, drive voltage V_{pp} , is applied to generating transducer 14. Transducer 12 acts as a sense transducer for a feedback loop including amplifier 45 and feedback circuitry 46. The feedback loop can control the frequency response and the
25 amplitude of motion of the microstructure.

 Alternatively, as shown by dashed line 48 in Figure 11, both transducers 12 and 14 may act as generating transducers when the microstructure functions as a source. In this embodiment, the feedback loop
30 would be eliminated.

 It is also possible to connect the microstructure of the present invention in a circuit so it functions both as a source and a receiver. That is, for example, it may act as both a microphone and speaker at audible
35 frequencies.

 As discussed, the fabrication process allows for the fabrication of thin transparent film sandwiches that

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can act as windows 18 (see Figures 1A-1B). When a mechanical vibration (bending) is applied to the microstructure, stresses may cause a change in transmittance and index of refraction of the thin film.

- 5 A change in index of refraction and absorption properties (elasto-optic properties) of the window section can be used to modulate and/or deflect light.

- As an optical device, the microstructure of the present invention can provide inexpensive phase plates
10 in optical systems which are shrinking in size due to requirements of larger number of optical components in a small package and portability of such systems.

- The present invention has been described in terms of a number of embodiments. The invention, however, is
15 not limited to the embodiments depicted and described. Rather, the scope of the invention is defined by the appended claims.

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WHAT IS CLAIMED IS:

1. A microfabricated acoustic source or receiver structure, comprising:
 - a substrate of a first material, said substrate
5 having first and second sections wherein said first section is thicker than said second section;
 - a membrane of a second material supported by said substrate, the thickness of said membrane less than that of said second section;
 - 10 means for inputting or sensing mechanical energy in said substrate and said membrane; and
 - wherein said second section of said substrate has a preselected region from which said first material has been removed.
- 15 2. The structure of Claim 1 wherein said first material is silicon.
3. The structure of Claim 2 wherein said second material is silicon nitride.
4. The structure of Claim 1 wherein said
20 inputting means includes a piezoelectric transduction film.
5. The structure of Claim 4 wherein said transduction film includes a zinc oxide layer disposed between layers of a conductive material.
- 25 6. The structure of Claim 1 wherein the thickness of said first section is between about 500 and 550 microns.
7. The structure of Claim 6 wherein the
30 thickness of said second section is between about 40 and 100 microns.

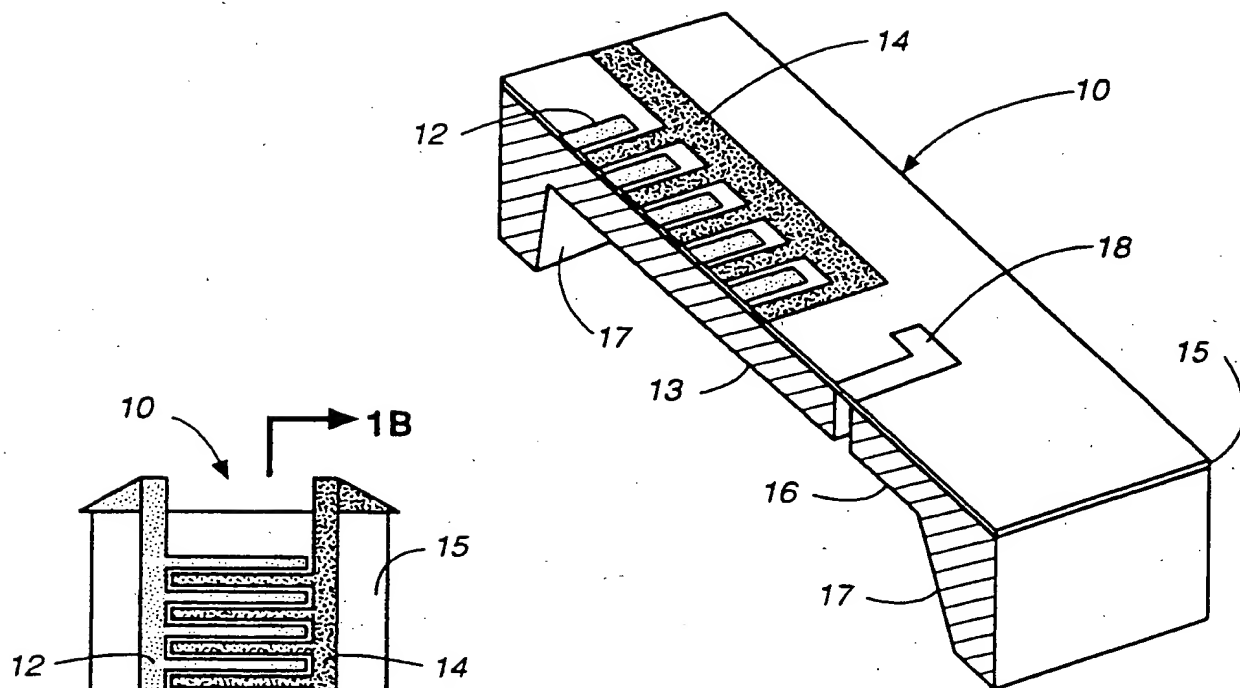
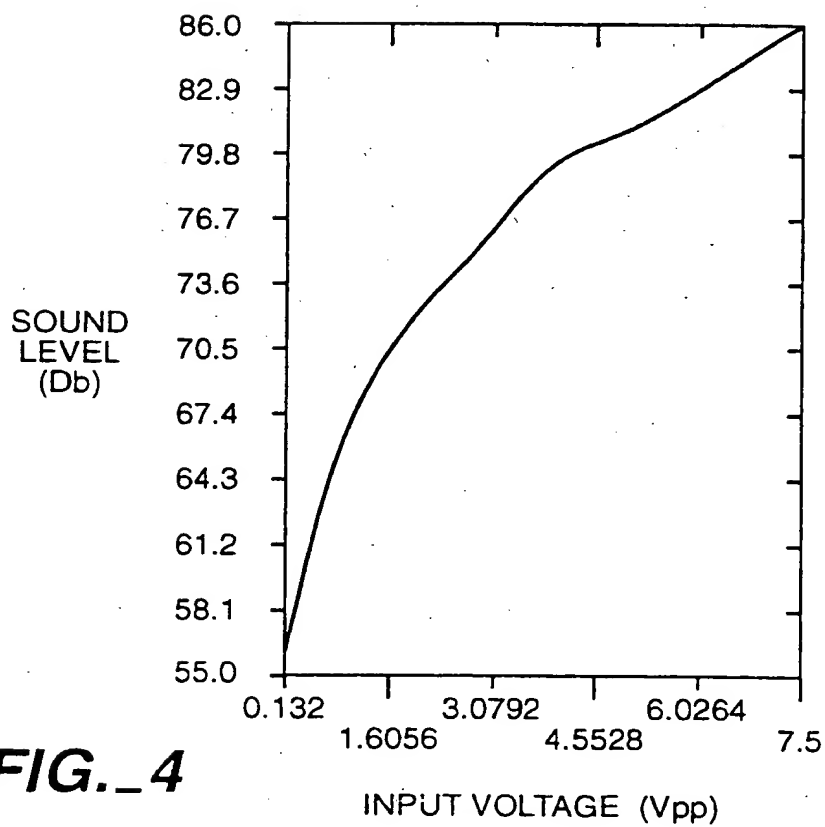
-16-

8. The structure of Claim 6 wherein the thickness of said second section is between about 50 and 70 microns.

9. The structure of Claim 7 wherein the
5 thickness of said membrane is between about one and four microns.

10. The structure of Claim 7 wherein the thickness of said membrane is about two microns.

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**FIG. 1B****FIG. 1A****FIG. 4**

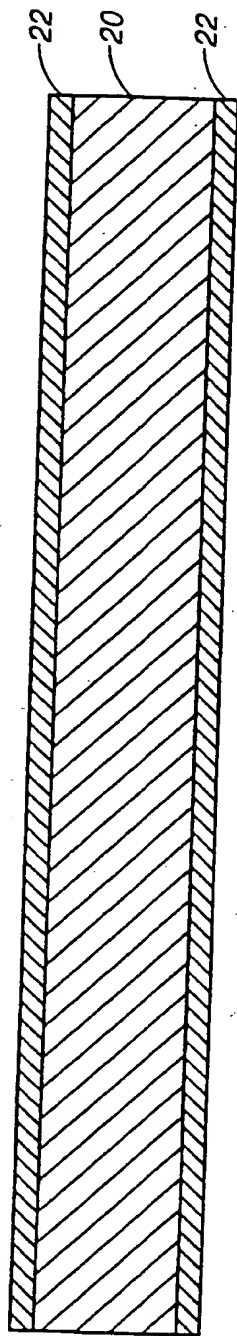


FIG. 2A

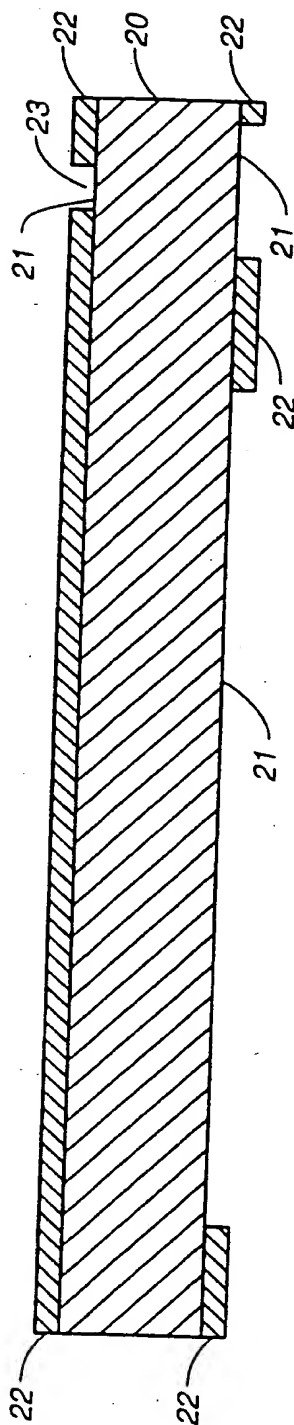


FIG. 2B

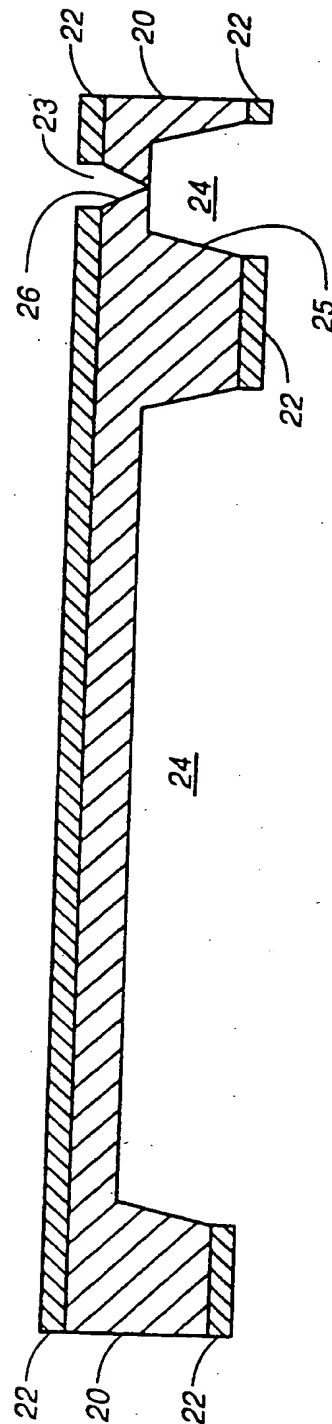


FIG. 2C

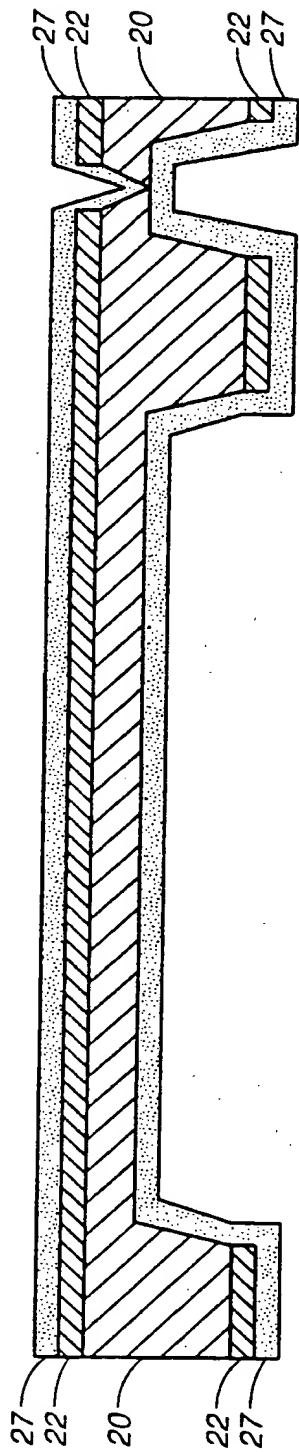


FIG. 2D

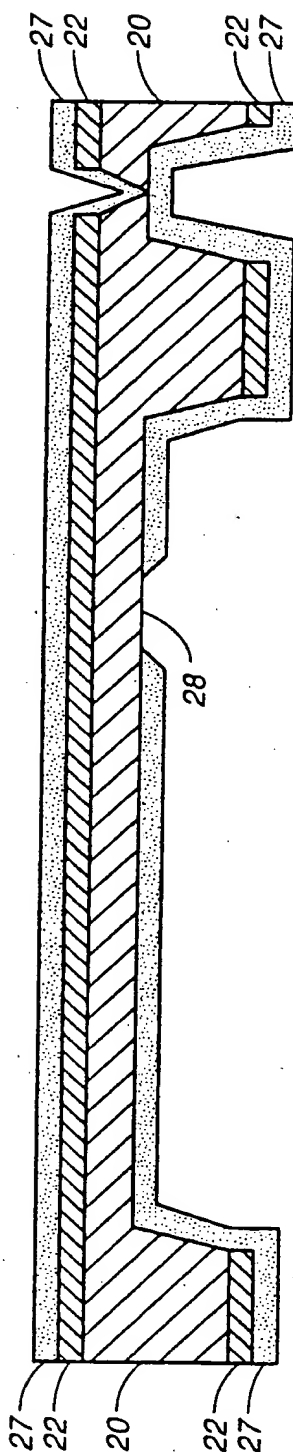


FIG. 2E

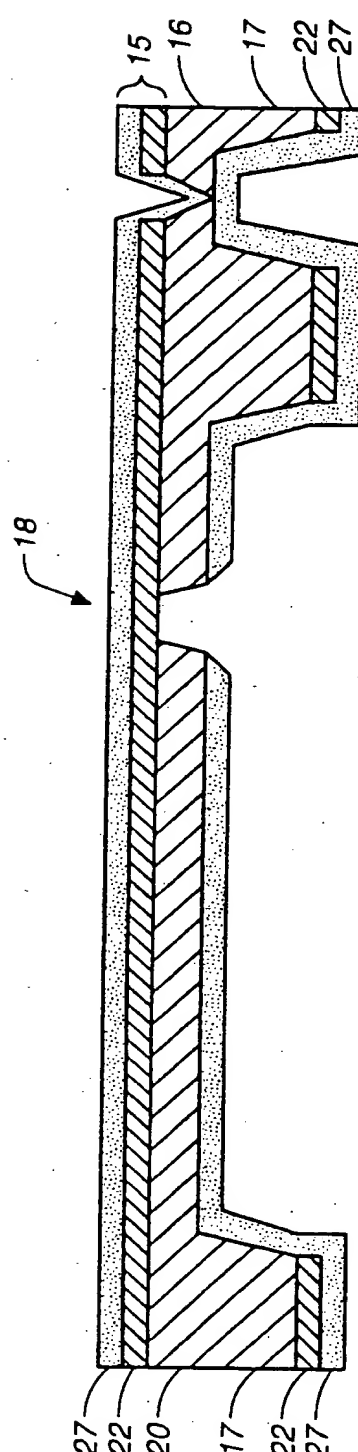


FIG. 2F

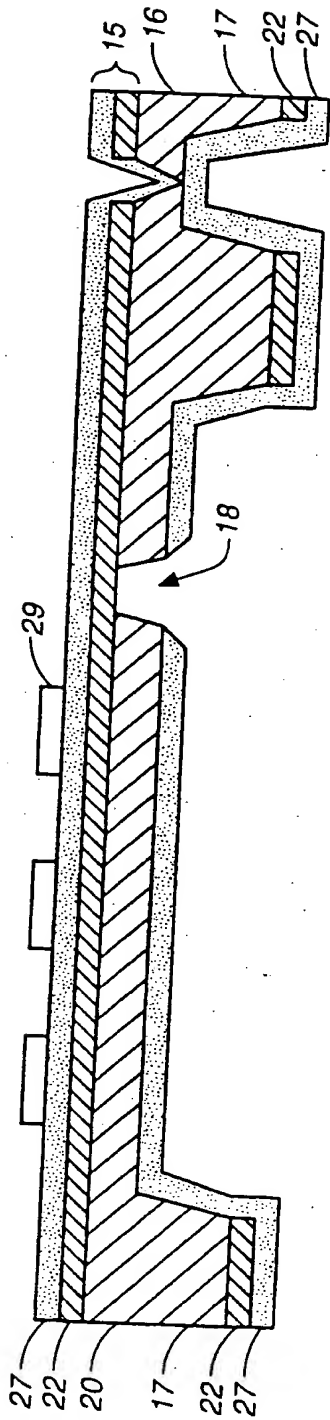


FIG. 2G

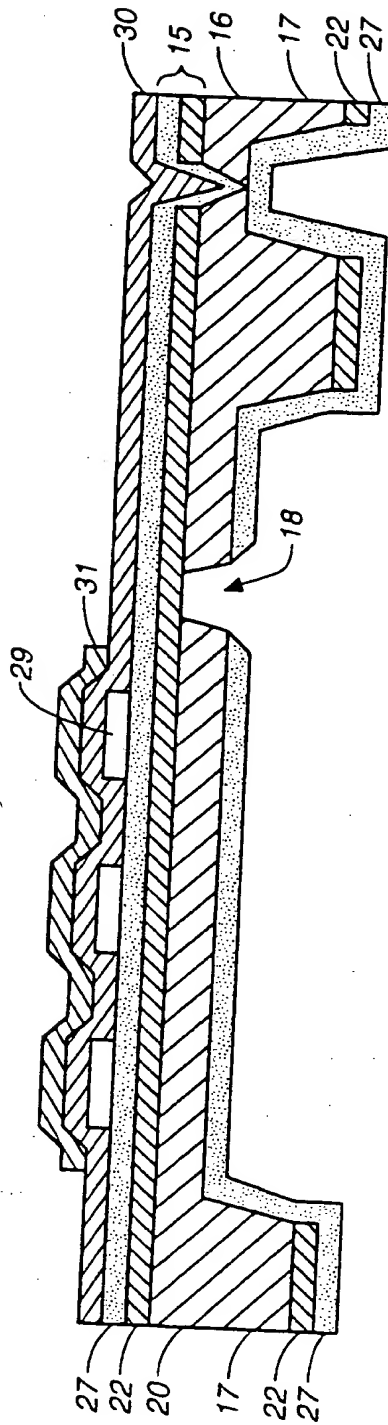


FIG. 2H

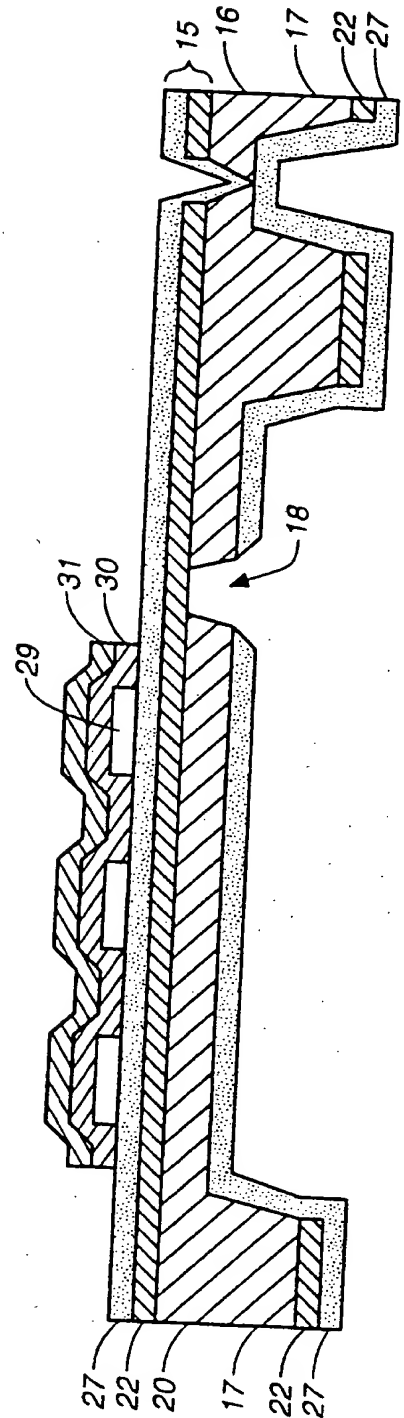


FIG. 2I

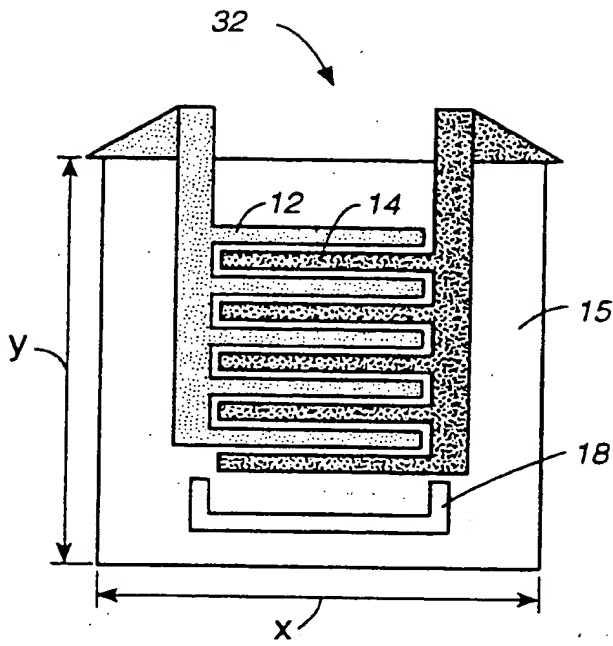


FIG. 3A

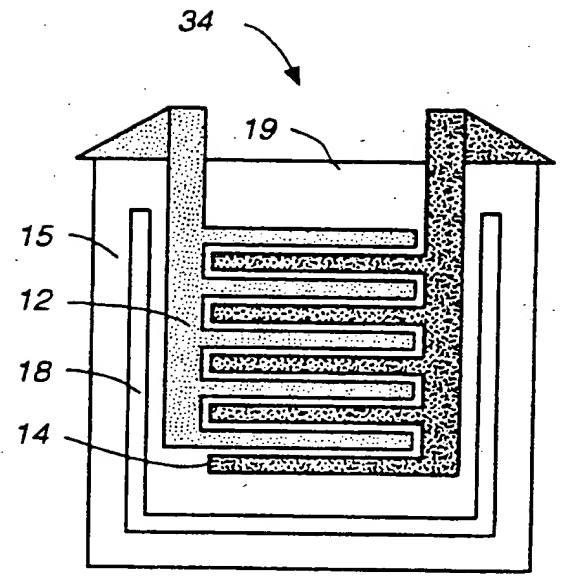


FIG. 3B

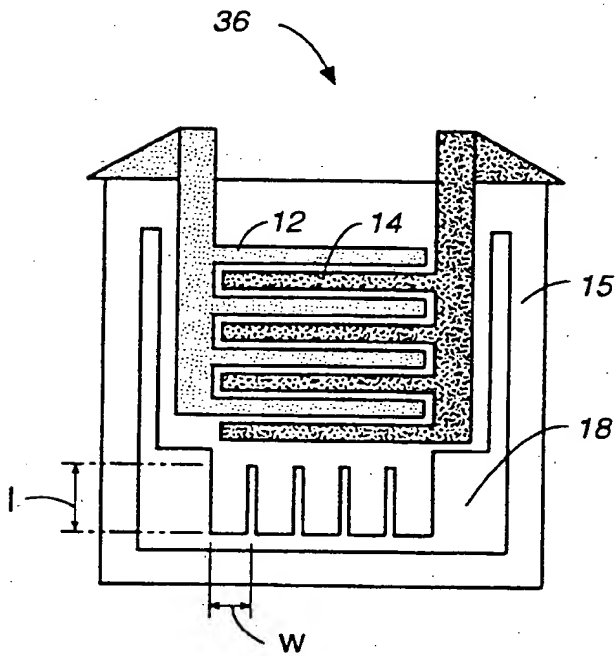


FIG. 3C

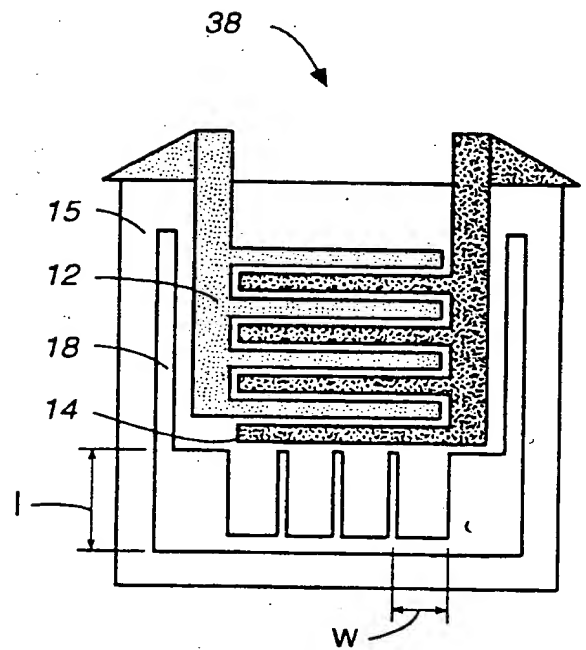
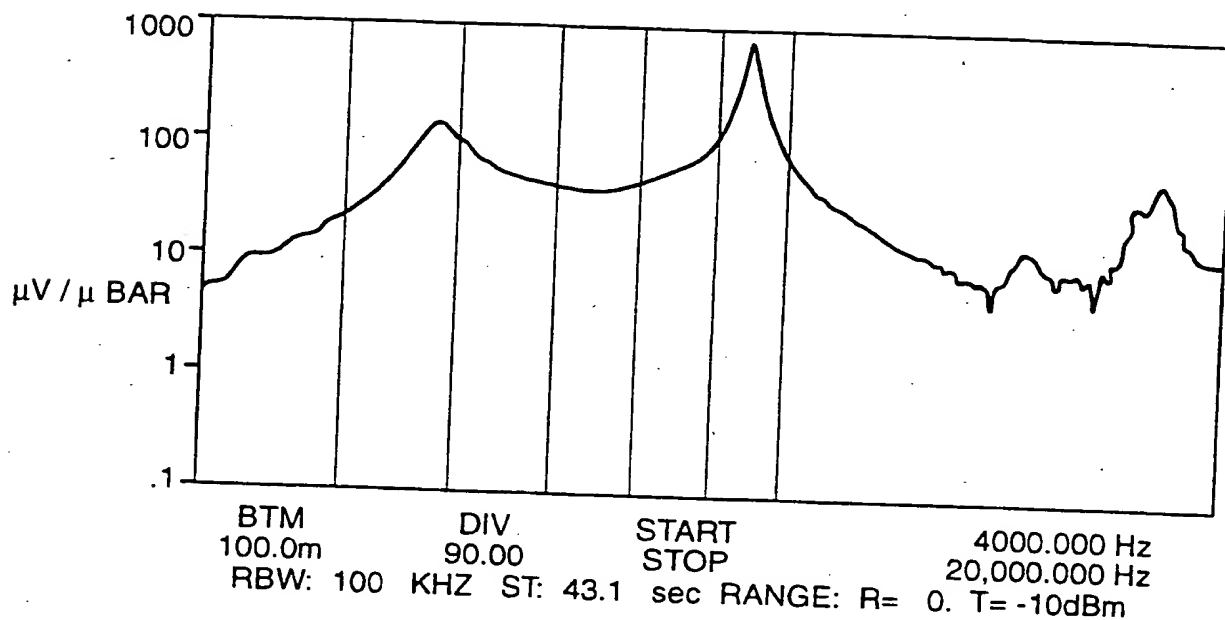
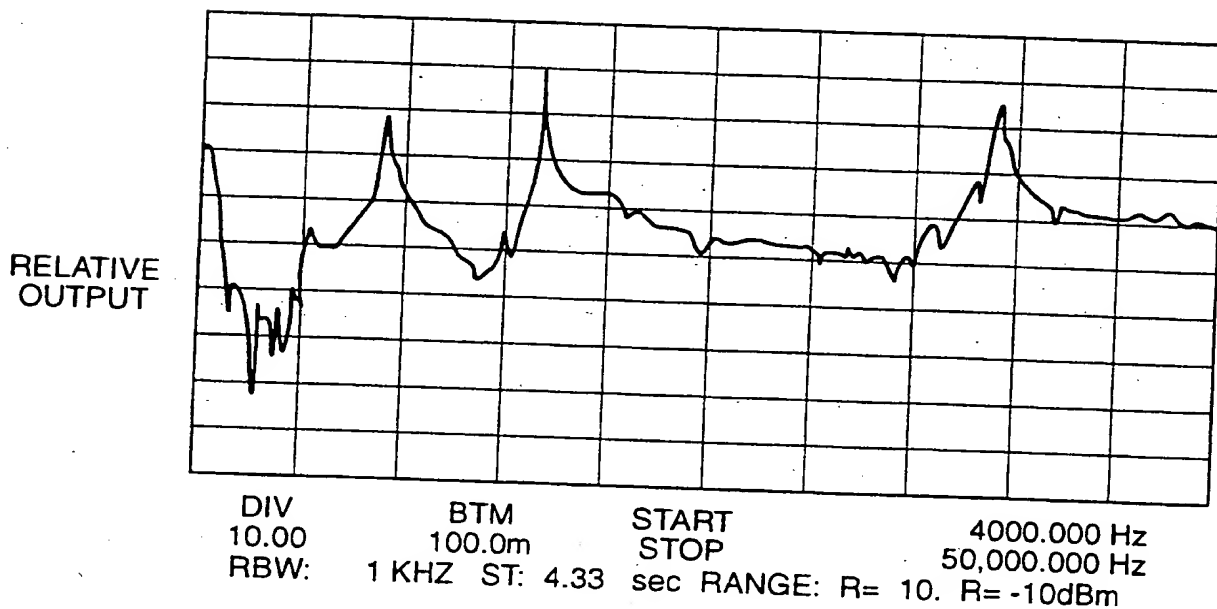
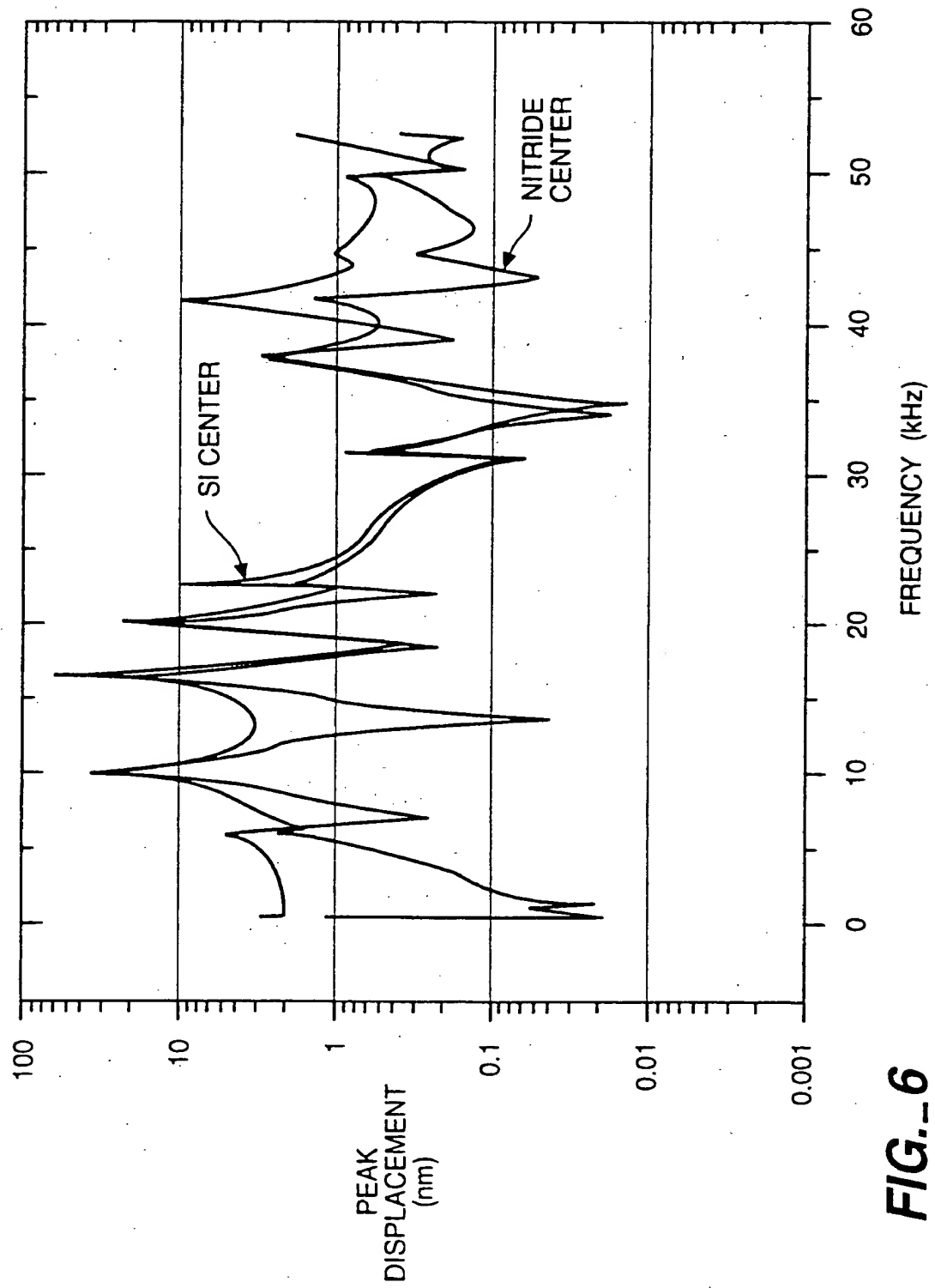


FIG. 3D

**FIG._5A****FIG._5B**

**FIG. 6**

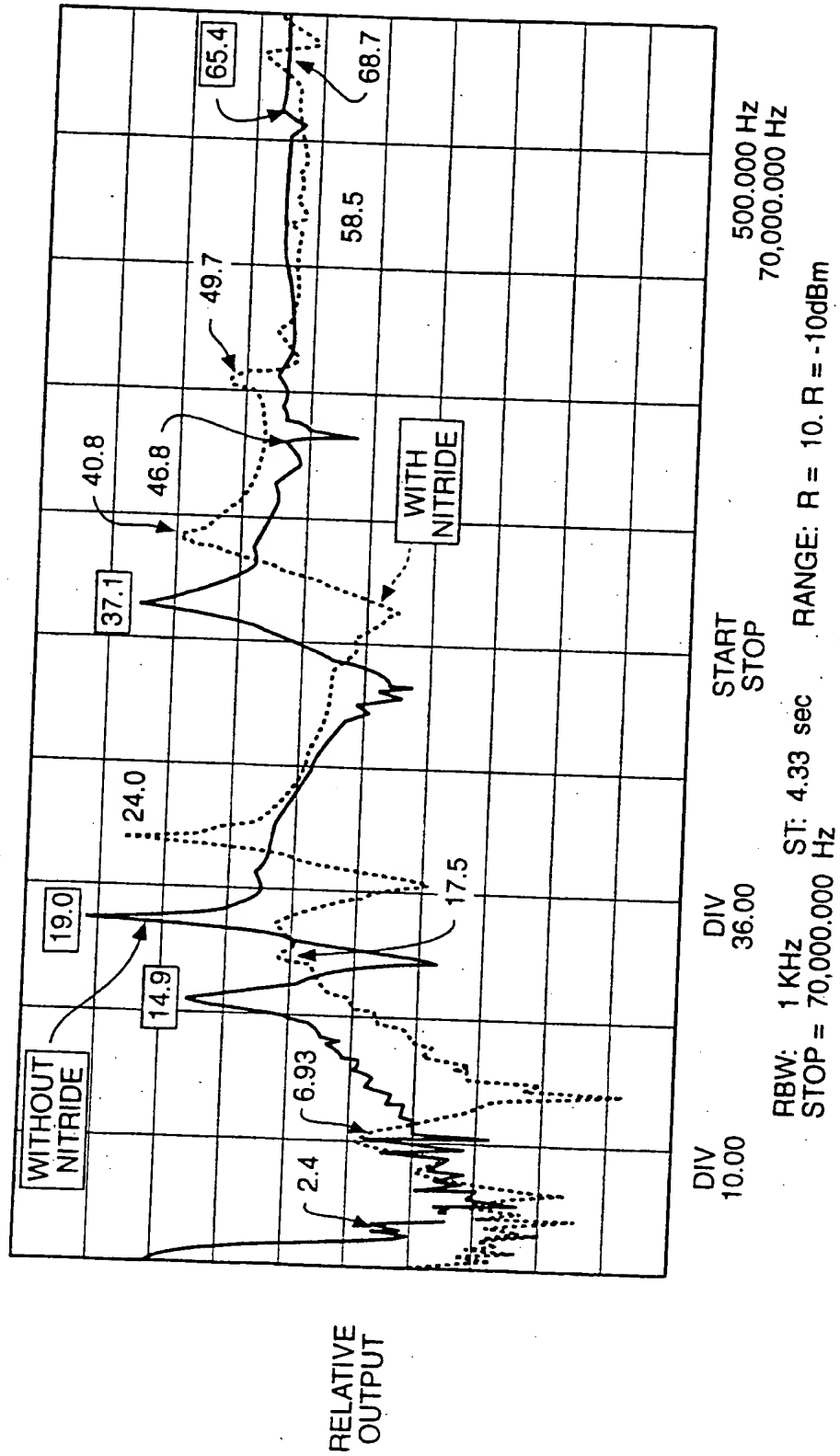
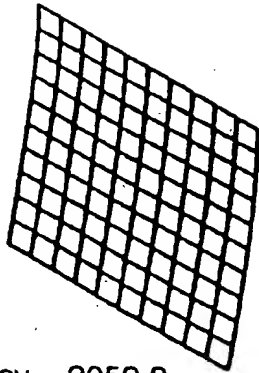
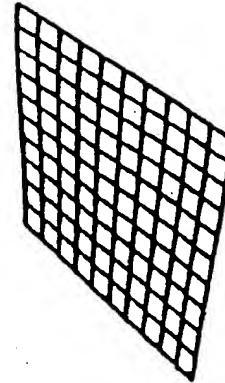


FIG. 7



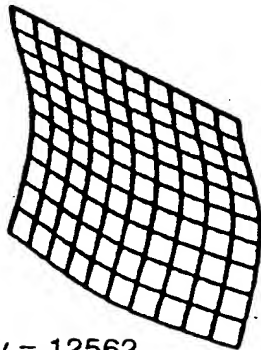
MODE 1
Frequency = 2059.8
Air wavelength = 16cm

FIG._8A



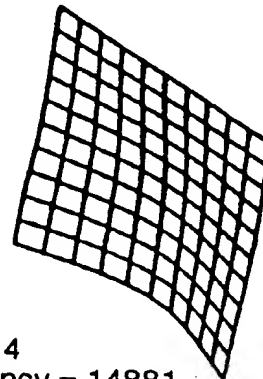
MODE 2
Frequency = 4876
Air wavelength = 6.77cm

FIG._8B



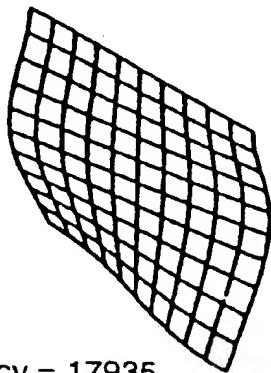
MODE 3
Frequency = 12562
Air wavelength = 2.63cm

FIG._8C



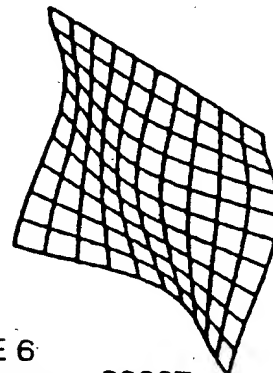
MODE 4
Frequency = 14881
Air wavelength = 2.21cm
Measured mode frequency > 14.9kHz

FIG._8D



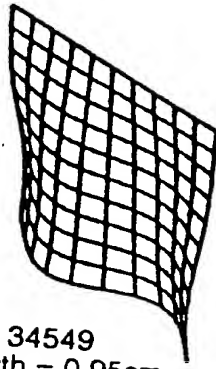
MODE 5
Frequency = 17935
Air wavelength = 1.84cm
Measured mode frequency > 19.0kHz

FIG._8E



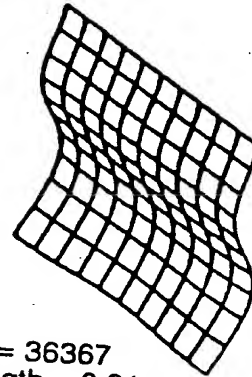
MODE 6
Frequency = 30607
Air wavelength = 1.08cm

FIG._8F



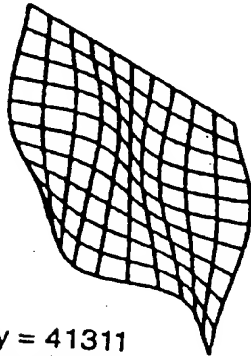
MODE 7
Frequency = 34549
Air wavelength = 0.95cm

FIG._8G



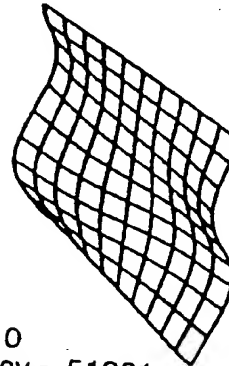
MODE 8
Frequency = 36367
Air wavelength = 0.91cm
Measured mode frequency > 37.1kHz

FIG._8H



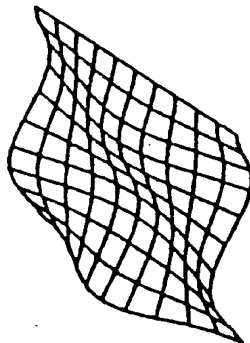
MODE 9
Frequency = 41311
Air wavelength = 0.8cm

FIG._8I



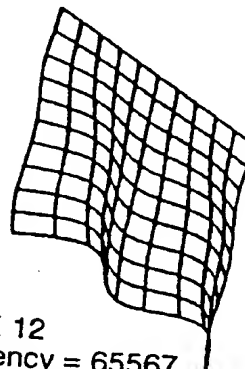
MODE 10
Frequency = 51261
Air wavelength = 0.64cm

FIG._8J



MODE 11
Frequency = 55360
Air wavelength = 0.596cm

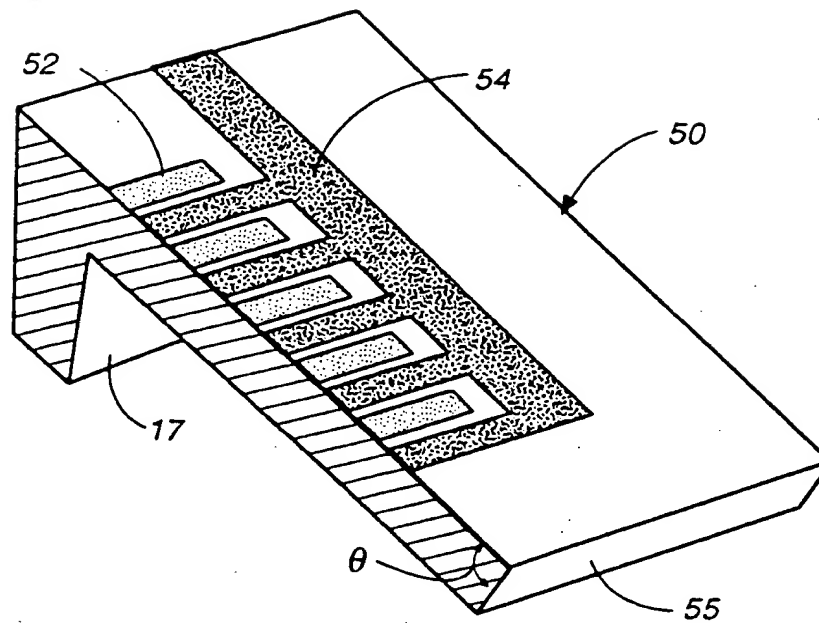
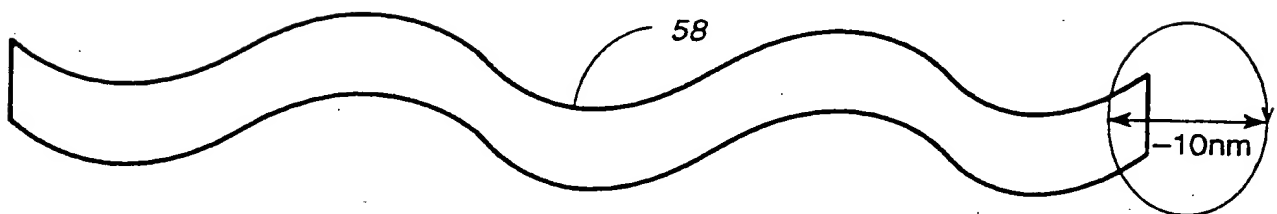
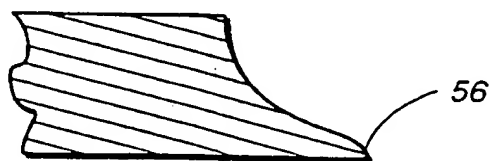
FIG._8K



MODE 12
Frequency = 65567
Air wavelength = 0.5cm
Measured mode frequency > 65.4kHz

FIG._8L

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**FIG. 9A****FIG. 9B****FIG. 9C**

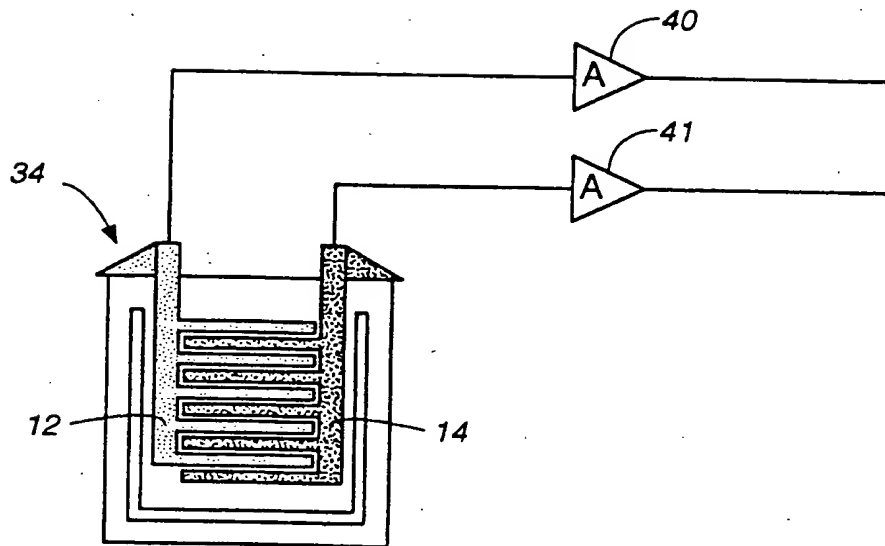


FIG. 10

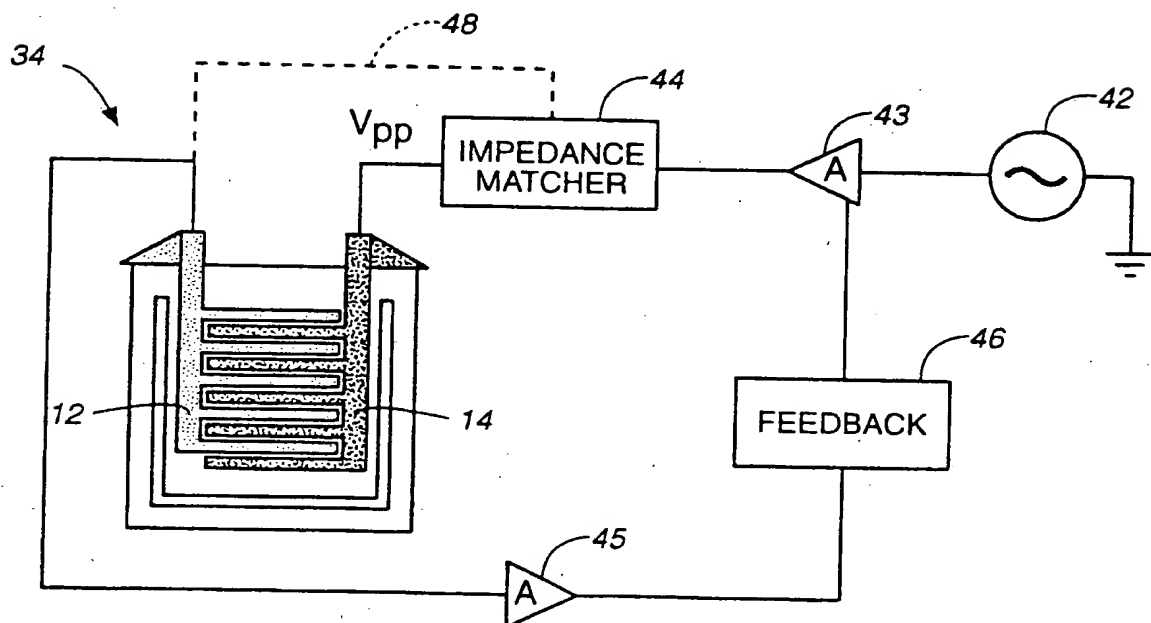


FIG. 11

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US94/05644

A. CLASSIFICATION OF SUBJECT MATTER

IPC(5) :H04R 25/00, 3/00

US CL :381/173, 113

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 381/173, 113, 191; 367/181; 310/313R

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

USAPS

search terms: silicon oxide, zinc, oxide, aluminum, silicon, microphone, transducer, condenser, layer

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US, A, 5,129,262 (WHITE et al.) 14 July 1992 (14.07.92), see figures 1 and 3.	1-10
X	US, A, 4,783,821 (MULLER et al.) 08 November 1988 (08.11.88), see figure 2.	1-10
X, P	US, A, 5,248,912 (ZDEBLICK et al.) 28 September 1993 (28.12.93), see figures 23 through 27.	1-10

☐ Further documents are listed in the continuation of Box C.☐ See patent family annex.

* Special categories of cited documents:	*T	later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
*A document defining the general state of the art which is not considered to be part of particular relevance	*X	document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
*E earlier document published on or after the international filing date	*Y	document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
*L document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	*Z	document member of the same patent family
*O document referring to an oral disclosure, use, exhibition or other means		
*P document published prior to the international filing date but later than the priority date claimed		

Date of the actual completion of the international search

06 AUGUST 1994

Date of mailing of the international search report

SEP 22 1994

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